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Review of passive solar heating and cooling technologies

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ABSTRACT

Heating, ventilating, and air-conditioning (HVAC) are parts of the major energy consumption in a building. Conventional heating and cooling systems are having an impact on carbon dioxide emissions, as well as on security of energy supply. In this regard, one of the attempts taken by researchers is the development of solar heating and cooling technologies. The objective of this paper is to review the passive solar technologies for space heating and cooling. The reviews were discussed according to the working mechanisms, i.e. buoyancy and evaporative effects. The advantages, limitations and challenges of the technologies have been highlighted and the future research needs in these areas have also been suggested.

Contents

1. Introduction

Generally, building sector consumes 35.3% of final energy demand [1]. Parts of the major energy consumption in buildings are the heating, ventilating, and air-conditioning (HVAC) systems. They are indoor climate controls that regulate humidity and temperature to provide thermal comfort and indoor air quality. With total amount of this HVAC's energy consumption in buildings, whether is the space heating or cooling being the dominant, they are closely related to the local climate condition. Heating systems are to provide or collect and store the solar heat, and retain the heat within the building. In contrast, cooling systems are to provide cold or protect the building from direct solar radiation and improve air ventilation. Space heating is the most important building energy user in cold countries, whereas, air conditioning is a major contributor to peak electricity demand in hot climate countries or during summer. For instance, in the United Kingdom, energy used for space heating was about 50% of the service sector energy consumption in 2004 [1,2]. On the other hand, air-conditioning load accounts for 40% of peak load during the summer in Shanghai. These heating and cooling loads are having an impact on CO_2 emissions, as well as on security of energy supply [1,3]. Therefore,

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Table 1
Solar heating and cooling technologies by active and passive designs.

	Heating	Cooling
Active solar Uses electrical or mechanical equipment, such as pumps and fans, to increase the usable heat in a system	• Uses solar collector where the absorber component absorbs solar radiation energy, converts into heat, and transfers the heat to a transport medium or fluid that flowing through the collector. The collected solar energy is hence carried from the fluid to a heat exchanger or storage tank that satisfying heating needs. • Solar collectors: devices such as flat plate, parabolic tough or evacuate tube.	• Uses the collected solar heat as energy source of air-conditioners, commonly known as solar assisted air-conditioning systems. • Devices: chillers such as absorption and adsorption chillers, solid or liquid desiccant systems.
Passive solar Without using active mechanical devices; the system do not use or uses only small amount of external energy	• Able to gain or trap heat through passive solar energy. Heat from solar radiation is absorbed, stored or used to preheat ventilation air. • Solar collectors: building components such as facade or roof.	• Generates and channels airflows, hence remove heat and create cooling effects; natural ventilation is among the most common type. • Devices: building components such as facade or roof.

renewable energy has become vital energy sources for heating and cooling, particularly solar energy that utilise cost-free solar radiation from the sun.

Solar heating and cooling technologies can be driven by solar thermal or photovoltaic. However, photovoltaic is beyond the discussion in this paper. Solar thermal driven heating technologies utilise passive or active solar energy to collect solar radiation and transform the energy into usable heat. The passive relates to building envelope design whereas the active relates to the use of solar collector to heat a fluid. Table 1 describes solar heating and cooling mechanisms through active and passive designs. The objectives of this paper are to review the passive solar technologies for space heating and cooling and identify the research needs in these areas. The reviews were discussed according to the working mechanisms, i.e. buoyancy and evaporative effects. Many facades designs applied the former mechanisms while the latter is relatively more common for roof designs.

2. Passive solar air heating and natural ventilation via buoyancy effect

Passive solar heating and natural ventilation technologies share similar working mechanism. The driving force which controls the airflow rate is the buoyancy effect, whereby the airflow is due to the air temperature difference and so as the density difference at the inlet and outlet. Usually, the facades are designed in flexible functions basis whether to trap or store the heat; or create air movement that causes ventilation thus cooling effect. Table 2 summarises some of the selected literature reviews of passive solar facade and roof designs which includes the studies of collector performance, cost and energy analysis, findings and recommendations.

2.1. Trombe wall

The classical Trombe wall is a massive wall that covered by an exterior glazing with an air channel in between (without dampers A and B in Fig. 1). The massive wall absorbs and stores the solar energy through the glazing. Part of the energy is transferred into the indoor of the building (the room) through the wall by conduction. Meanwhile, the lower temperature air enters the channel from the room through the lower vent of the wall, heated up by the wall and flows upward due to buoyancy effect. The heated air then returns to the room through the upper vent of the wall. Some of the challenges with this classical Trombe wall design are as follows:

(1) Low thermal resistance. When small amount of the solar energy absorbed by the wall, e.g. during the night or prolonged cloudy periods, some heat flux is transferred from the inside to the outside, which results in excessive heat loss from the building [4].
(2) Inverse thermo-siphon phenomena occur during winter, at night or non-sunny day. When the wall is colder than the indoor temperature, reverse air circulation from the upper vent to the lower vent causes the air being cooled and hence decrease the room temperature [4,5].
(3) The uncertainty of heat transfer due to air movement in enclosures that heated by solar energy. The solar intensity is not constant and periodical. Any change in solar intensity could cause temperature fluctuations of the wall [5].
(4) The influences of channel width and the dimensions of the inlet and outlet openings affect the convection process and hence affect the overall heating performance [5,6].
(5) Low aesthetic value [7].

Studies have been carried out to improve the classical Trombe wall design. The improvement can be classified into three aspects, i.e. inlet and outlet air openings control, thermal insulation designs, and air channel designs.

By installing adjustable dampers at the glazing and adjustable vents of the wall, the classical Trombe wall can be beneficial for winter heating and summer cooling [6,7]. By referring to Fig. 1, in winter, damper B is closed while damper A, lower and upper vents are left open to circulate the heated air return to the room. Whereas during summer, damper A and upper vent are closed. The buoyancy forces generated by the solar heated air between the warm wall and glazing draws room air from the lower vent and the heated air is then flows out to the ambient through open damper B. Thus, during summer the Trombe wall facilitates room air movement for summer cooling. Alternatively, in the case of Trombe wall that without adjustable damper at the glazing, the upper and lower vents are closed when the outdoor temperature is lower than the indoor [4].

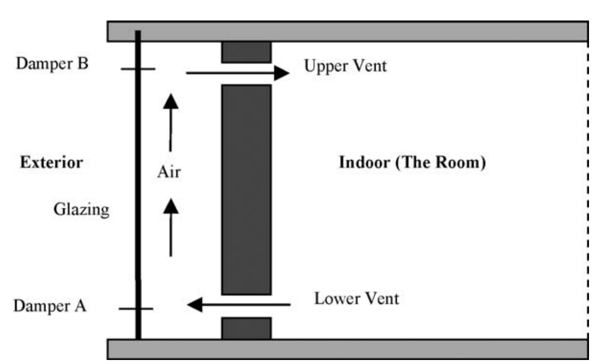

Fig. 1. Schematic diagram of classical Trombe wall (without dampers).

Table 2
Summary of some of the selected previous researches.

Facade/roof designs	Special features	Performance			Cost and energy analysis	Benefits/findings	Limitations/recommendations	Ref.
		Given conditions	Temperatures (instantaneous efficiency, %)	Flow rate				
Solar chimney	Vertical, similar to Trombe wall.	$I = 650\,W/m^2$; air gap depth = 0.2 m.	Exhaust air = 39 °C; indoor air = 30 °C (41%).		N.A	• Temperature rise and air velocity increased with solar radiation. • Temperature rise decreased with air gap depth. • No reverse air flow circulation was observed even at large gap of 0.3 m.	N.A	[42]
Solar wall	Similar to Trombe wall, consists of glass cover, air gap, black metallic plate, insulator.	$I = 406\,W/m^2$; $T_a = 30\,°C$; height = 1 m; air gap depth = 0.145 m.	Exhaust air = 42 °C; indoor air = 28 °C.	Mass flow rate = 0.016 kg/s.	N.A	• Temperatures increased with increased wall height and decreased gap.	• In very hot season, providing residents' comfort is insufficient by natural ventilation but it is able to reduce the heat gain which in turn reduces the cooling load.	[43]
Double facades	(i) Outer skin: glaze; inner skin: glaze. (ii) Outer skin: PV panel; inner skin: glaze.	Cavity width = 0.8 m; inlet area = outlet area.	N.A	(i) Airflow rate = $0.27\,m^3/ms$. (ii) Airflow rate = $0.36\,m^3/ms$.	PV facade increased electricity conversion efficiency by reducing the cell temperature.	• PV facade increased the efficiency of PV cells when outdoor air temperature is higher than the indoor.	• The outer skin temperature of PV panel increased depending on the degree of transparency.	[44]
Single-sided heated solar chimney	Adjacent walls are insulated.	Length = 1 m; breath/height = 0.1; inlet temperature = 20 °C.	Exhaust air = 33 °C.	Airflow rate = 0.5 kg/s.	N.A	• The airflow rate reaches maximum when breath/height = 0.1.	• The optimised height can be determined according to the optimised section ratio of breath to height and available practical field conditions.	[45]
Solar chimney	Under hot and humid climate conditions, studies included during clear sky, partly cloudy and cloudy days.	(i) Clear sky: $T_a = 35\,°C$; $I = 800\,W/m^2$; wind velocity = 2.6 m/s. (ii) Partly cloudy: $T_a = 34\,°C$; $I = 594\,W/m^2$; wind velocity = 2.5 m/s. (iii) Cloudy day: $T_a = 32\,°C$; $I = 509\,W/m^2$; wind velocity = 1.8 m/s.	(i) Exhaust air = 38 °C; indoor air = 33 °C. (ii) Exhaust air = 36 °C; indoor air = 32 °C. (iii) Exhaust air = 33 °C; indoor air = 32 °C.	N.A	N.A	• Solar chimney can reduce indoor temperature by 1.0–3.5 °C compared to the ambient temperature of 32–40 °C.	• Indoor temperature can be further reduced by 2.0–6.2 °C with combination of spraying of water on the roof.	[34]
Roof solar collector	Air gap and openings of roof solar collector.	N.A	N.A	10–100 m^3/h.	Insignificant extra cost of construction.	• Larger air gap larger and equal size of openings induced higher rate of airflow rate.	• Insufficient natural ventilation to satisfy residents' comfort. • Another device such as Trombe wall might be needed to improve comfort performance.	[21]

Table 2 (*Continued*)

Facade/roof designs	Special features	Performance			Cost and energy analysis	Benefits/findings	Limitations/ recommendations	Ref.
		Given conditions	Temperatures (instantaneous efficiency, %)	Flow rate				
Roof-integrated water solar collector	Roof integrated, combining the conventional roof and flat plat solar collector by replacing water-coil and internal insulation with water pond and metallic sheet.	N.A	N.A	N.A	150–200 USD/m^2 compare to 160–220 USD/m^2 of conventional air-conditioner; taking one-third of construction time that represents 15 USD/m^2. Average daily energy absorbed = 0.68 GJ. Annual energy = 247 GJ.	• Able to control heat delivery to adapt with the environmental conditions. • Able to create heating or cooling effects. • Provide hot domestic hot water during winter.	Large area of roof is needed.	[25]
Roof solar collector	Single and double pass designs.	I = 500 W/m^2; T_a = 0 °C; mass flow rate 2000 kg/h.	(i) Single pass: supply air = 12 °C; indoor air = 8 °C (27%). (ii) Double pass: supply air = 18 °C; indoor air = 13 °C (39%).	N.A	Choosing suitable fan is important to reduce initial investment and operating cost.	• Instantaneous efficiency of double pass was 10% higher than single pass collector whether spacing heating or natural ventilation.	• Two or more shorter collectors in parallel are recommended instead of one longer collector.	[24]

Note: I = solar intensity; T_a = ambient air temperature; N.A = not applicable; Ref. = references.

Insulation levels of glazing and storage wall influence the surface temperatures and thereby the fluid flow rate. These two thermal insulation methods have their own strengths for different climate conditions. For winter heating, increasing the thermal resistance of glazing is generally more advantageous as this reduces the heat loss through glazing while making use of conductive heat transfer from the storage wall to the room. Richman and Pressnail [8] introduced a low-e coating on a spandrel glass to minimize the radioactive losses to the exterior. Gan [6] proposed that using double glazing could increase the flow rate by 11–17%. Jie et al. [7] introduced the PV-Trombe wall concept that not only improve the aesthetical aspect but also able to capture the heats and simultaneously reduce the PV cells temperature. On the other hand, insulating the interior surface of the storage wall for summer cooling can avoid excessive overheating due to south-facing glazing [6]. Matuska and Sourek found that there was no effect on indoor comfort when sufficient insulation layers were applied on the storage wall [9].

In addition, composite Trombe–Michel wall has also been studied to overcome the heat loss from the inside to the outside of building [4]. The concept of composite Trombe–Michel wall is similar to the traditional Trombe wall except there is an insulating wall at the back of the massive wall (Fig. 2). The thermal energy can be transferred from outside to the interior air layer by conduction through the massive wall. Then it can be transferred by convection while using the thermo-circulation phenomenon of air between the massive wall and the insulating wall. During non-sunny days, winter or at nights, the vents in the insulating wall are closed. Hence, due to greater thermal resistance of this design, the thermal flux that going from indoor to outdoor is reduced.

Typically, Trombe wall is a sensible heat storage wall. Another innovative design of Trombe wall is filling phase change materials (PCM) into the masonry wall to store the latent heat. For a given amount of heat storage, the phase change units require less space and are lighter in weight compared to mass wall [10]. Therefore, it is convenient for building retrofitting. Studies indicated that concrete–PCM combination Trombe wall can be used to develop low energy house as it is an effective energy storage wall [11,12]. Nwachukwu and Okonkwo [13] had found that by applying a coating of superior absorption vigour on the exterior of storage wall could enhance the heat absorption and heat transfer across a Trombe wall. However studies on PCM properties for Trombe wall are yet to be developed to get the optimum results.

Apart from that, energy and air movement in the channel of a Trombe wall are induced by natural convection. Thus, the design parameters of Trombe wall channel are also factors that might affect the convection process [5]. A parametric study has shown that airflow rate was almost unaffected by channel width, however airflow rate was increased with the height of the wall [6].

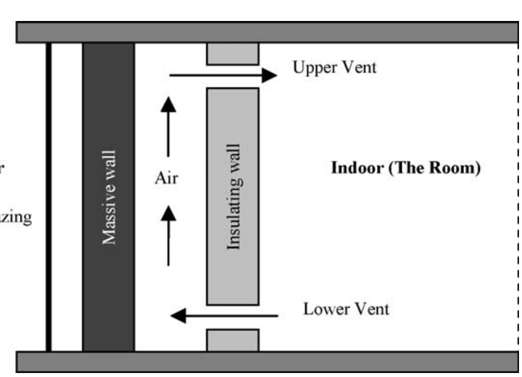

Fig. 2. Schematic diagram of composite Trombe–Michel wall.

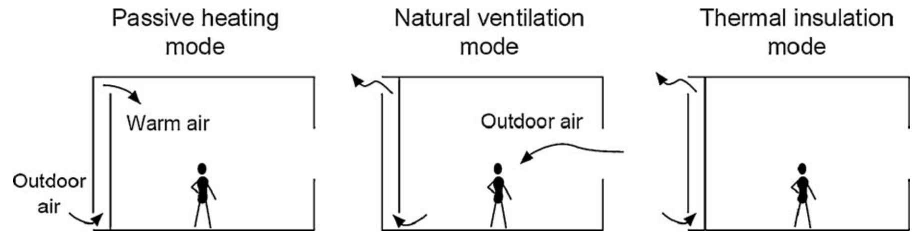

Fig. 3. Solar chimney operation modes.

2.2. Solar chimney

The purpose of the solar chimney is to generate airflow through a building, converting thermal energy into kinetic energy of air movement. The driving force which controls the airflow rate through the solar chimney is the density difference of air at inlet and outlet of the chimney. It provides ventilation not only for cooling but also heating if fan is used to direct the heated air into the building. When solar chimney is attached to wall, the working mechanism is similar to Trombe wall. It operates as passive heating by supplying warm air that heated up by the solar collector into the room. For cold or moderate climate, when the outdoor temperature is lower than the indoor temperature, solar chimney is functioned as passive cooling where natural ventilation is applied. However for hot climate, when the outdoor temperature is higher than the indoor, it operates as thermal insulation to reduce heat gain of the room. These three different modes are as illustrated in Fig. 3 [14]. The simplest and most obvious layout is to have a vertical chimney. Nonetheless, this may not be architectural attractive in term of aesthetics aspect. So a cheaper and less visually obtrusive format is to lay the collector along the roof slope while for greater height, a combination of both types may be used [15,16]. Some of the selected studies of solar chimney performance were as shown in Table 2. They are such as typical solar chimney, vertical types that similar to Trombe wall and double facades which hybrid with PV panel. Studies showed that solar chimneys are able to warm the air or ventilate the room air to create cooling effect even during cloudy days. However, depend on the local climate conditions, when solely solar chimney cannot satisfy the thermal comfort, other active or passive heating and cooling systems might need to apply.

2.3. Unglazed transpired solar facade

Another facade design that able to serve as heating system without additional heat storage facility is the wall made of metal sheet with holes that operates as absorber to heat up the air. The schematic diagram of this type of solar collector is as illustrated in Fig. 4. This collector is known as unglazed perforated-absorber collector by the Air System Working Group of International Energy Agency (IEA) Solar Heating and Cooling (SHC) Task 14. Other researchers have named it as unglazed transpired solar collector, whereas the Conserval Engineering Inc. refers the product as Solarwall. The metal cladding is heated by solar radiation. With the help of ventilation fans, the solar heated air is drawn through the holes of transpired metal sheet. The heated air is then ducted into the building via a connection to the HVAC intake. This technology has been installed on a large number of sites in Canada. More detail descriptions and installations around the world can be found in references [17–19]. Table 3 summarises some of the case studies

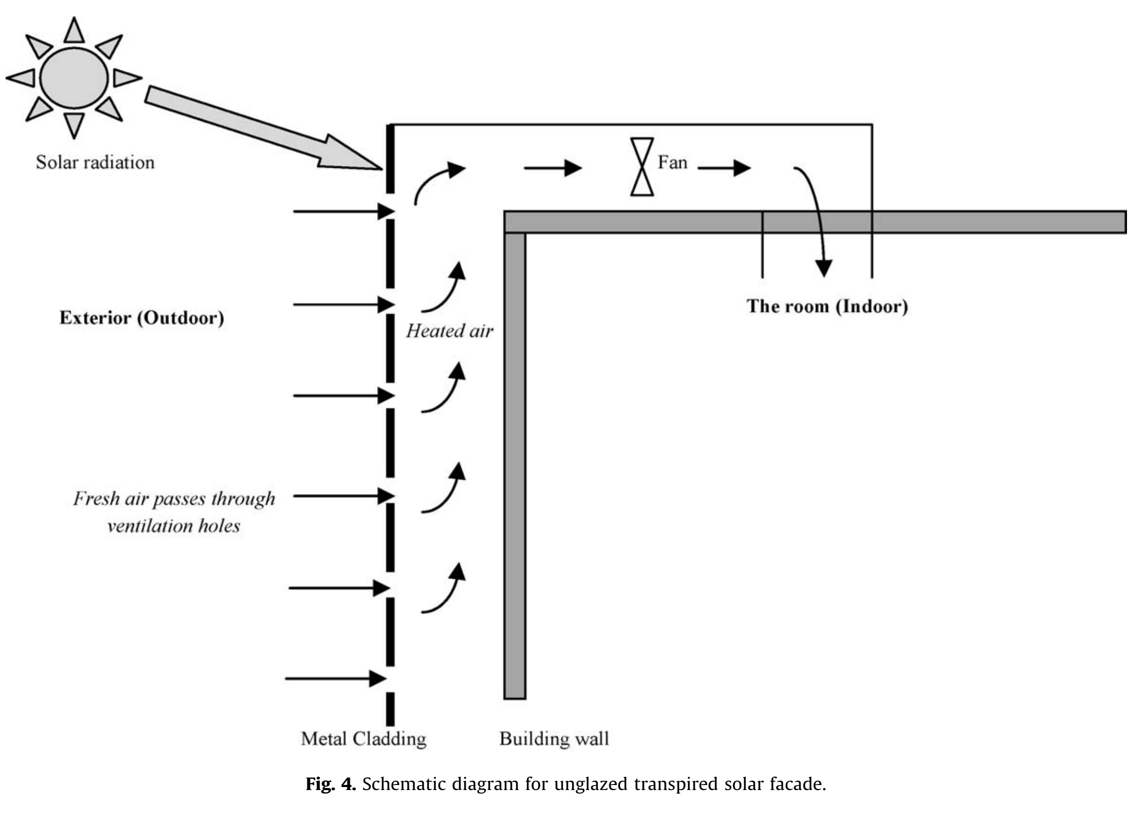

Fig. 4. Schematic diagram for unglazed transpired solar facade.

Table 3
Summary of some case studies performance results of unglazed transpired solar wall for space heating.

Case study	Collector area and type	Airflow rate ($m^3/h/m^2$)	Temperature rise	Efficiency	Energy saving	Cost analysis (reference year)	Reference
Ford Canada	1877 m^2; vertical wall; 2% porosity with 1% canopy	125	12 °C (sunny day)	57%	917 kWh/m^2/year	Cost of delivered energy = 25 USD/GJ/ year (1990)	[18]
GM, Oshawa	420 m^2 gross; 2% porosity on wall, 1% on canopy	72	13 °C (solar radiation: 500 W/m^2)	52%	754 kWh/m^2/year	Cost of delivered energy = 59 USD/GJ/ year (1991)	[18,46]
NREL Waste Handling Facility	27.9 m^2; 2% porosity	N.A	N.A	63–68%	N.A	N.A	[18]
Windsor Housing Authority	335 m^2; corrugated dark brown aluminium	N.A	N.A	N.A	195,700 kWh/year (estimated)	Estimated Saving: 4184 USD/year (2.2 cents/kWh of natural gas)	[47]
Combined PV/solarwall panel	Solarwall panel area = 1.1664 m^2; PV cells covered 24% of solarwall surface	100	N.A	(Solar radiation: 600 W/m^2) Thermal efficiency = 48%; combined efficiency = 51%	Energy saving = 500–1000 kWh/m^2/year; PV power = 18.5 W; estimated 50–100 kWh/m^2/year of electricity generated	N.A	[48]

performance results for space heating. Results showed that this heating system is able to save the premises energy consumption up to 1 MWh/m^2/year depends on the collector designs. Furthermore, in term of material cost, as compared to Trombe wall that using glazing, this elimination glazing design is able to reduce cost and it is suitable for retrofitting.

2.4. Solar roof

Methods of passive cooling by roof are such as water firm, roof pond, roof garden and thermal insulation. Solar roof ventilation may perform better than Trombe wall design in climates where the solar altitude is large. This is because roof collectors provide larger surface area to collect the solar energy and hence higher air exit temperature [20]. Nevertheless, Khedari et al. [21] observed that with only roof solar collector system, there is little potential to satisfy room thermal comfort. Additional device such as Trombe wall to be used together with roof solar collector would provide better cooling effect especially in hot climate. Dimoudi et al. [22,23] studied the thermal performance of the ventilated roof during summer and winter. The ventilated roof component consisted of reinforced concrete slab and insulation layer as the typical component but with an air gap between the insulation and the upper prefabricated slab. Results showed that there was no clear improvement of the thermal performance during the winter period but its main advantage is during the summer period, whereby the building is protected from the solar gains due to its insulation properties. On the other hand, Zhai et al. [24] has reported that the efficiency of double pass of air gap can induce more air change rate and hence is generally 10% higher than that of single pass roof solar collector (Table 2). Roof-integrated water solar collector that made of several layers of glass followed by water chamber and metallic sheet at the bottom was developed by Juanico [25] and could be used for domestic heating and cooling systems.

3. Passive solar cooling via evaporative effect

Passive solar cooling technologies which generate cold air could be found in the roof designs but it is not common for facade designs. Most of passive solar cooling technologies through facades are based on buoyancy mechanism that forces the air movement to ventilate the air in the room and thus creates cooling effect. This is as discussed in previous section as natural ventilation. In this section, the focus is to discuss on passive solar cooling via evaporative effect. Evaporative cooling is the oldest technique of cooling and may be applied in both active and passive systems. Conventional mechanical cooling systems that require high energy cost and harm the environmental have prompted the researchers to begin looking back at the evaporative technique and trying to improve its efficiency [26]. Hence it has been intensively used as evaporative cooler or heat exchanger in air-conditioning system. However, building integration of evaporative cooling is just a handful amount and yet to be developed.

3.1. Evaporative cooling

Amer [27] has found that among some passive cooling systems, evaporative cooling gave the best cooling effect, followed by solar chimney, which reduced inside air temperature by 9.6 °C and 8.5 °C, respectively. Evaporative cooling process uses the evaporation of water to cool an air stream. Basically water absorbs heat from the air (surrounding) to evaporate into vapour. Thus reduce the temperature of the air or surrounding. In Middle East wind towers were developed to scoop the cool wind into the building, which was made to pass over water cisterns to produce evaporative cooling and a feeling of freshness [14]. Evaporative cooling can be classified into direct and indirect evaporating cooling.

3.1.1. Direct evaporative cooling (DEC)

The principle underlying direct evaporative cooling is the conversion of sensible heat to latent heat. The air is cooled when water in the air steam is evaporated. The water in the air stream is supplied and recirculated continuously so that the water is removed by the air and yield the cooling effect. Some of the sensible heat of the air is transferred to the water and becomes latent heat by evaporating some of the water. The latent heat follows the water vapour and diffuses into the air. Thus the moisture of the supply air is increased after the process (Fig. 5a). In intermediate seasons in hot dry climates, direct evaporative cooling can offer energy conservation opportunities. However, the increase of moisture into the air stream during the process has reduced the cooling system efficiency. Cooling effect might not

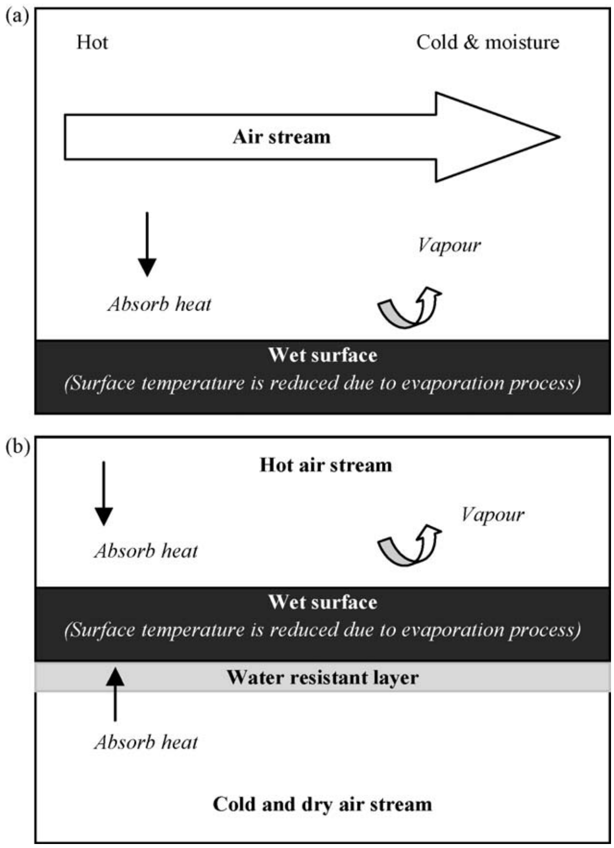

Fig. 5. Evaporative process for (a) direct evaporative cooling and (b) indirect evaporative cooling.

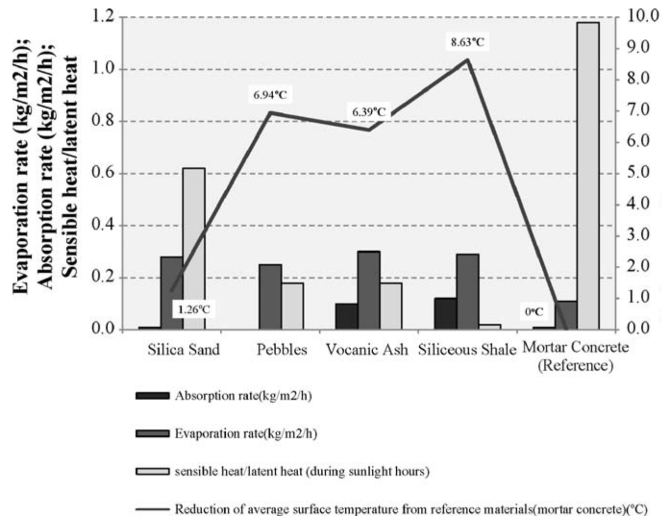

Fig. 6. Performance of roof materials on evaporative cooling effect.

sufficient especially in very humid climate and summertime. Therefore, the incoming air is usually dehumidified by forcing it through a desiccant to improve the cooling efficiency [28–31]. Joudi and Mehdi [32] introduced combination of membrane air-drying and evaporative cooling systems. The membrane constitutes of hollow fibers, i.e. cellulose acetate and polysulfone. The selective membrane allows for efficient separation of the water vapour from the air. The air is pre-treated (dried) by passing through the membrane before entering the evaporative cooling system and hence operated in drier air stream.

3.1.2. Indirect evaporative cooling (IEC)

As shown in Fig. 5b, IEC involves heat exchange with another air stream. These two air streams are separated by a heat exchanging wall, where one side of the wall is wet and another is dry. The working air passes through the wet side, while the product air passes through the dry side. The wet side absorbs heat from the dry side by water evaporation and hence cools the dry side. The wet air stream involves latent heat while the dry air stream involves sensible heat. Therefore, no additional moisture is introduced into the product air.

3.2. Building integration of evaporative cooling

One of the building integration applications of evaporative cooling is porous roof. During periods of precipitation, rainwater penetrates through the porous layer and is stored within the layer. The porous layer retains a significant amount of rainwater, which is released back into the atmosphere via evaporation during sunlight hours. When evaporation takes place, the surface temperature of the porous layer decreases due to the release of latent heat. Therefore, heat flux from the roof slab, which could raise the room temperature of the building, would also be reduced. When the air is at high humidity during night time or on cloudy days, the porous layer adsorbs moisture from the air and continues to cool the roof materials. Wanphen and Nagano [33] studied the performance of roof materials on evaporative cooling effect and the results were summarised in Fig. 6. Among the studied materials, siliceous shale which comprise of a high number of mesopores are effectively keeping surface moisture from vapour adsorption, is found to have the greatest evaporation performance. Due to the high absorption rate, this material is able to absorb more vapour during night time. The stored water from the precipitation period inside porous layers of siliceous shale evaporates and release more latent heat to the atmosphere during sunlight hours while silica sand, volcanic ash and pebbles yield more sensible heat (lowest value of sensible heat/latent heat). Moreover, its high evaporation rate tends to cool down the surface temperature. As a result, siliceous shale is able to reduce the roof surface temperature up to 8.63 °C as compared to mortar concrete.

Raman et al. [16] on the other hand developed solar air heaters for solar passive designs that cooperate with evaporation for summer cooling. The system consists of two solar air heaters with natural flow, one is on the roof another one is on the ground. The roof air heater acts as an exhaust fan, venting out the air from the room during sunshine whereas the air heater on the ground is functioned as air heater during winter and as an indirect evaporative cooler during summer. However the system performed well during winter but not for summer cooling. As a result, modifications were made whereby the south wall collector and a roof duct were wetted on the top side by an evaporative cooled surface were constructed. The results showed that the modified system was able to give better thermal comfort for both seasons. On the other hand, Chungloo and Limmeechokchai [34] carried out the studies by spraying water on the roof during partly and cloudy days under hot and humid climate in Thailand. They found that water spraying on metal ceiling is able to decrease indoor temperature. When the water evaporated, the surface temperature of the roof decreased and reduced the indoor temperature. However, higher solar radiation and ambient temperature gave better performance.

4. Passive solar: filling the gap of active solar technologies

Proper design of orientation, structure, envelope, construction materials of a building is important to control the thermal loads from the solar heat gain, hence reduce the HVAC size, which in turn

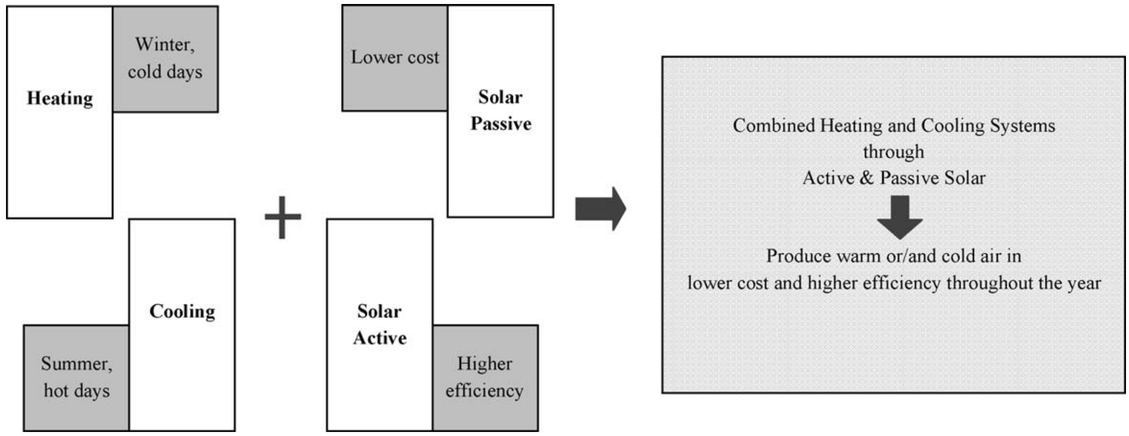

Fig. 7. Overcoming the limitations by combining heating and cooling systems, and the solar active and passive technologies.

enhancing the feasibility of solar cooling technologies. Solar passive features can add 0–15% to design and construction costs [35]. However paying this initial cost in return is long life energy saving. For instance, the solar H.P. Co-operative Bank building in India has demonstrated that solar passive designs, double glazing are able to reduce the total heat loss by about 35% [36].

Integrating the solar heating and cooling systems in building envelope is a necessity if the systems are to be economically feasible. Typically, it could be roof or facade integrations such as wall, balcony, awning or shade of the building. The integration is only possible if the design of the solar system is included in the design of the building itself. The major component of any solar system is the solar collector. They are usually black or dark in colour to maximise the absorptance and minimise the emittance of radiation that reaches the surface. Unfortunately, black surfaces are not always considered aesthetically acceptable in all cases, e.g. facade integration. Therefore, active solar collectors are often been considered as technical element [37,38]. They are installed separately from the building or confined to the roof top so that they are less visible to minimise the building aesthetic impact [9,39]. Consequently, the installation cost of an active solar heating or cooling system might consider as additional initial cost of the building. On the other hand, passive solar designs are building integrated whereby facades or roofs are part of the heating or cooling system components. This in turn reduces initial cost. For instance, the unglazed transpired solar facade cost about 7–10 USD/ft^2, plus installation [40]; whereas a typical active solar water heater cost about 134 USD/ft^2 or 59 USD/ft^2 after incentives [41].

Moreover, passive solar designs are the function flexibility. Designs such as Trombe wall and solar chimney are able to provide warm air or create cooling effect depend on the climate needs by damper controllers. As compared to the active solar thermal technologies, the solar collectors are only meant for collecting heat. The heated air or water is either directly used by building occupants or to be used as heat source for heating or cooling systems. The combined heating and cooling systems require an additional system that not as simple as shifting the damper controllers.

5. Summary

Even though a lot of active and passive solar designs for heating and cooling have been developed, they generally have their own limitations. Active solar technologies need developments of smaller capacity, simpler, low cost and more maintenance and operational friendly systems. Whereas passive solar designs might not sufficient to provide indoor thermal comfort, particularly regions that have extreme climates.

The research areas that need to be carried out to improve the existing solar technologies performance and market acceptance are the system efficiency, architectural aesthetic, and cost effectiveness aspects. They in fact have been carried out intensively. Otherwise, research on development of a combination system could be an alternative. Studied done by Maria et al. [39] suggested that solar collector should be conceived as part of a construction system which is providing active and passive solar benefits, flexible enough to interface with the other building elements and able to adapt to different buildings. As illustrated in Fig. 7, combination of heating and cooling systems is able to harness the solar energy throughout the year in countries with hot and cold seasons, whereas hybrid of solar active and passive technologies would improve the system efficiency and cost effectiveness. Hence, limitations of the technologies are overcome by each other's advantages and making the overall solar heating and cooling system feasible, more marketable and increase the public acceptance.

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